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CONTINUOUS PLANT COVER THE KEY TO SOIL AND WATER CONSERVATION

By

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Nature performs her marvelous feat of building soil by means of "holding" and "developing" actions. These actions are performed simultaneously, mostly by the many thousands of types and species of plants that inhabit the earth. In the process, Nature develops progressively the most suitable plants for each combination of soil and climatic conditions.

Soil building is a complex, ages-long process that begins with rock. It involves weathering of rock, fragmentation of rock by roots of growing plants, grinding and transportation of rock fragments by glacial action, growth and decay of plants and animals, and the activity of small mammals and microscopic organisms. As plantlife becomes established on the surface, organic residues begin to accumulate. These are broken down by rainfall and heat and the activity of mammals, fungi, and insects. The soluble portions are leached downward by rain and water from melting snow, and the soil becomes darker in color. At first, the layer of soil is very thin. It becomes thicker as plant residues and other organic substances accumulate on the surface, and the humus they produce penetrates deeper into the soil. Humus accumulates faster at the surface than at lower depths, so the upper part of the soil is the most productive.

Throughout the soil-building process, the surface is protected by a blanket of plant growth which holds the soil in place. Plants of a low order, such as moss and lichens, usually are first. They form a protective covering over the rock surface to catch and hold dust. This cover also holds the soil in place as it starts development from the surface downward (fig. 1). As soon as the rocky surface has changed sufficiently to support higher forms of plantlife, the mosses and lichens are gradually replaced by the next higher plant form in the ecological scale. Further improvement is followed by the invasion of still higher forms of plantlife until the climax species is reached.

If this plant cover is removed, or is reduced so that there is not enough to protect the surface, the soil begins to erode and deteriorate. The succession of plantlife which was active in building the soil may be thrown into reverse if erosion is permitted to progress far enough. Thus, lower forms of plantlife would follow in succession.

The "holding" action of plant cover on the soil was not appreciated until after Nature's balance between soil-building and soil-destroying forces had been upset by its removal. Removal of the native plant cover exposed the bare soil to the full force of wind and water. The erosive action that followed stopped the soil-building process and began a trend toward soil deterioration. Even now, too few people realize that the "holding" action is essential for soil and water conservation, and, in turn, soil improvement.

The part played by wind in the soil erosion process and methods for its control were presented in other papers (33, 36).[1]

Function of Plant Cover in Water-Erosion Control

The major role of plant cover is to protect the soil from the force of falling raindrops (5, 12, 22). We know now that raindrop impact is the primary cause of erosion on cultivated land (fig. 2). The raindrops have the energy, in striking bare soil, to dislodge soil particles from the soil mass. They can move some soil downhill by their splashing during hard rains. Nearly all of the sediment removed from fields by water erosion, however, is the result of the combined action of surface flow and raindrop splash (22). The raindrops dislodge soil particles and feed them into the surface flow. The splashing also gives to shallow surface flow the turbulence it needs for transportation of the dislodged soil particles.

The amount of damage caused by falling raindrops is proportional to the kinetic energy they possess. It has been estimated that the kinetic energy of falling raindrops ranges from 1,000 to 100,000 times the work capacity of surface runoff. Erosion caused by raindrop splash is

[1] Numbers in parenthesis refer to Literature Cited.

Figure 1.--Formotion of residuol soil. Generations of liverworts growing on solid rock have gradually brought about decomposition of the surfoce portions of the rock. The addition of orgonic matter in the form of decaying remoins of liverworts hos caused the formation of obout one-half inch of soil. Peeling bock the liverworts from the rock surfoce picks up the soil.

actually sheet erosion, since its force is uniformly distributed over the entire area on which the rain falls.

The force generated by surface flow is determined by its concentration and speed of movement downhill. Flowing water gains energy by gaining mass as it concentrates at the foot of a slope, or by gaining velocity as it flows down a steep slope. Owing to the nature of the source of its energy, surface water does not flow evenly over the surface of a field, but rather causes the formation of rills and gullies.

Plant cover controls splash erosion by intercepting the raindrops and absorbing their energy (fig. 3). It also protects the infiltration capacity of the soil. On bare land, the beating action of raindrops during all but light rains breaks down the clods and soil aggregates, and forms a tight layer at the surface. This sharply reduces the infiltration capacity of the soil and increases runoff. Plant cover prevents the formation of this tight surface layer.

Effectiveness of the cover is proportional to its amount and distribution. Weight, in terms of pounds per acre, and coverage, in terms of percent of the ground surface that is covered, are practical measurements of effectiveness that are of about equal value (24). The closest indication of effectiveness is obtained, however, when weight is multiplied by coverage to give an index of "effective weight"--combination of total weight and soil coverage.

The growth forms of the different crops influence their effectiveness in protecting the soil from raindrop impact. Close-growing crops of medium height, such as oats, wheat, and vetch, have almost indentical values for the same weight of cover. Tall-growing crops, such as sweetclover and cotton, provide less protection than close-growing crops for the same weight of cover in amounts above 1,000 pounds per acre (24). Tall, coarse crops provide less protection than close-growing crops because of their more open canopy and because their foliage intercepts raindrops some distance above the ground. When these drops fall to the ground, they still can attain erosive velocities.

For 90 percent effectiveness, approximately 2,500 pounds (dry weight) per acre of close-growing crops or 4,000 pounds of tall, coarse crops are required (24). Below this point, effectiveness declines rapidly as the amount of cover is reduced and the difference between growth forms becomes less important. At 1,000 pounds per acre there is no significant difference in the two kinds of crops; both are 60 percent effective.

It is generally recognized that, under most systems of management, land cropped to grass and trees does not present as serious an erosion problem as land devoted to cultivated crops. In fact, erosion is practically nonexistent on land protected by ample plant cover, regardless of the kind and nature of the cover.

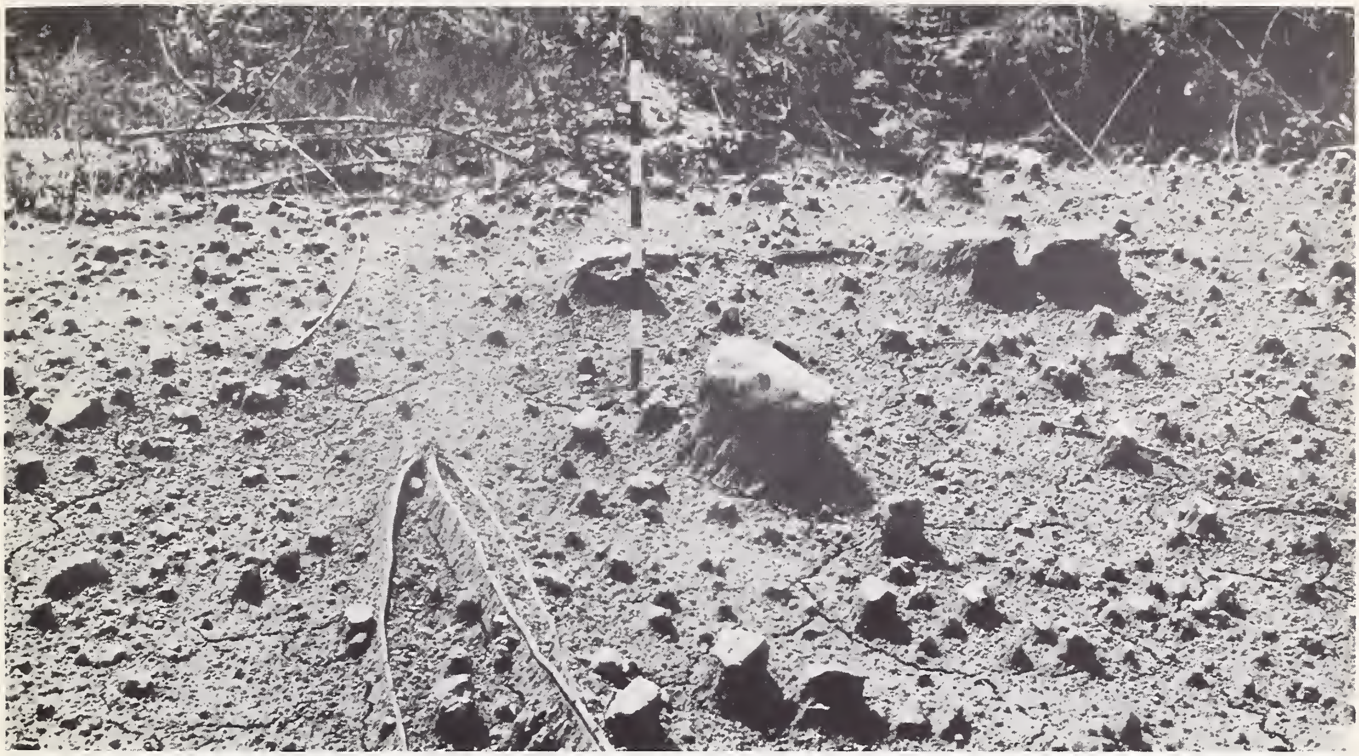

Figure 2.--About 2 inches of soil were removed from this South Carolina plowed field during one rain, mainly as a result of raindrop splash. The stone-capped pedestals show that the force causing the erosion was applied from above, as by falling raindrops, and not from the side, as by flowing surface water. The dead plant roots in the foreground protected the soil immediately beneath them whereas that between and to the sides was splashed away. Little erosion took place in the background where the surface of the ground was protected by plant cover.

Likewise the loss of water as runoff is directly affected by the plant cover. As plant cover decreases or deteriorates, erosion and runoff losses become progressively higher (table 1).

TABLE 1.--Average soil loss per acre in tons and runoff in percent of rainfall annually over a 14-year period (23)

Treatment	Soil	Runoff
Continuous bluegrass	0.34	12.0
Rotation: corn, wheat, clover	2.78	13.8
Continuous wheat	10.09	23.3
Continuous corn	19.72	29.4
Fallow	41.65	30.7

Effect of Plant Cover Under Cropping Systems

The effectiveness of any cropping system in reducing soil and water losses depends largely upon the proportion of close-growing vegetation used, and the length of time and season of the year when it occupies the land. Crops that provide protective cover during the months of erosion-producing rains are especially valuable for conserving soil and water (30).

A crop rotation of cotton, wheat, and sweetclover reduced annual soil loss by 74 percent and annual runoff of water by 34 percent, compared with continuous cotton, during a 21-year period at Guthrie, Okla. (10). Both wheat and sweetclover greatly reduced erosion, but the amount of soil removed from the wheat plot was 6 times as great as from the sweetclover. During a 1.69-inch rain on July 21, 1950, (with 5-, 15-, and 30-minute intensities of 5.64, 3.84, and 2.30 inches per hour, respectively), the continuous cotton plot lost 41.65 percent of the rainwater as runoff and 1.835 tons of soil per acre. The wheat plot lost 47.51 percent of the rainfall as runoff and 0.098 ton of soil per acre. The sweetclover plot lost no water or soil, and a bermudagrass sod plot lost only 0.47 percent runoff and no soil.

In Nebraska, land that had been fall plowed and then planted to corn the following spring lost almost twice as much water and four times as much soil as land that had been subsurface-tilled at the same time and was protected with wheat residues (11). Combined wheat stubble and straw, left undisturbed on the soil surface, reduced the loss through runoff to 2.39 percent of the rain that fell, and the soil loss to 1 percent of that on bare land. Land that had been disked and planted to oats, after the corn had been harvested and the stalks removed, lost 10.852 tons of soil per acre from January 1 to June 30, 1942. Adjacent plots, protected by

Figure 3.--Plant cover intercepts falling raindrops, absorbs their kinetic energy, and eliminates their damaging impact action on the ground surface.

cornstalk residue and subsurface tilled before the oats were planted, lost 0.613 ton of soil. Plots planted to corn, after the preceding sweetclover crop had been turned under, lost 12.364 tons of soil from 1 rain. An adjacent sweetclover plot, which was subsurface tilled before being planted to corn, lost only 1.152 tons of soil.

Green manure was 65 percent less effective in controlling erosion when it was plowed under in the fall than when it was left on the surface and the land cultivated with sweeps (15). The soil loss was 57.8 tons per acre, where the green manure was plowed under, compared with 20.22 tons where the vegetation was left on the surface. Adjacent land that was planted continuously to corn lost 111.7 tons of soil per acre annually during a 6-year period. The annual soil loss on land under small grain was 16.8 tons per acre, but only 0.68 ton on land under grass grown for hay.

Land in Georgia that was planted continuously to cotton lost an average of 24.95 tons of soil per acre annually during the period 1940-47 (6). This rate of soil loss was reduced to 15.39 tons by using a 2-year crop rotation consisting of corn-crotalaria and cotton-vetch. A 3-year rotation of oats-lespedeza, lespedeza, and cotton reduced erosion still further to 3.38 tons per acre annually. Of the 10.15 tons of soil lost per acre during the 3 years of the crop rotation, 7.08 tons per acre were lost during the year the land was cropped to cotton. Only 0.25 ton per acre was lost during the year this land was in lespedeza.

From April to September 1940, unmulched land in Georgia lost 12.57 tons of soil per acre, compared with 0.2 ton lost from mulched land (17). During this period, 32.75 percent of the rain that fell was lost as runoff from the unmulched land, compared with 1.43 percent lost from the mulched land. A plot, which had been disk-harrowed, planted to Kobe lespedeza, and mulched with straw, lost as runoff only 1.2 percent of the rain that fell and 0.24 ton of soil per acre from April 1940 until the end of that year (16). A companion plot, similarly handled except for being mulched, lost 24.2 percent of the rain as runoff and 12.62 tons of soil per acre during the same period.

A plot in Mississippi, planted continuously to cotton, lost as runoff 58 percent of a total rainfall of 130.7 inches during a 2-year period (21). The runoff amounted to as much as 96 percent of the precipitation from individual rains. Soil loss on this plot exceeded 195 tons per acre for the 2-year period. The runoff from broomsedge in an old field was only slightly more than 1 percent of the rainfall, and from an oak forest it was even less. Runoff from these 2 classes of cover during individual storms did not exceed 5.05 and 3.10 percent of rainfall, respectively,

and erosion was almost negligible. The cultivated land lost 4,300 times as much soil per acre as the forested plot.

It was found in Idaho that a wheatgrass type of vegetation minimized flash runoff and erosion even under conditions of torrential rainstorms and steep slopes (8). As long as the character of the cover was unchanged and its original density maintained, it could be grazed by livestock and wild game without greatly reducing its effectiveness in controlling erosion and runoff.

In Virginia, mature stands of close-growing crops prevented excessive rates of runoff from Dunmore silt loam on slopes up to 25 percent, but high rates of runoff occurred on plots planted to corn (20). Serious soil losses occurred when corn was planted on slopes exceeding 10 percent. Hay crops provided almost complete protection against both runoff and erosion.

Plots of Houston clay in Mississippi were covered with straw at the rate of 2 tons per acre immediately after cultivation. They lost only 0.1 ton of soil per acre from July 1 to December 31, 1942 (39). An adjacent plot, which was cultivated but not covered with straw, lost 21 tons of soil per acre during the same period. The straw-covered plot lost 6 percent of the 14.83 inches of rain that fell, whereas the unmulched plot lost 44 percent.

In South Carolina, Cecil clay loam mulched with Kobe lespedeza and crimson clover hay at the rate of 4 tons to the acre lost only 0.75 ton of soil during the period August 1939 to January 1942. This compares with 89.15 tons of soil lost per acre from adjacent land that was not mulched (25). An excellent demonstration of the effect of plant cover as an erosion-control measure occurred on August 21-22, 1946, when a 4.64-inch rain fell. A plot which had been disked so as to leave as much as possible of the residues from the preceding crop on the soil surface lost 275 pounds of soil per acre. But a similar plot which had been plowed and was without plant cover lost 1,767 pounds (26).

When stones larger than 2 inches across were removed from a stony soil in New York, the water loss was doubled and the soil loss tripled during a 6-year period, compared with a similar area where the stones remained in place (19). A mulch reduced the annual water loss from 1.93 inches to 0.16 inch and the annual soil loss per acre from 9,132 pounds to just a trace during a 3-year period, in comparison with a similar soil that was fallowed.

Erosion losses were as much as 149 times greater from unmulched plots than from plots protected by straw mulch in Illinois (37). During these tests 91 percent of the ground surface of the plot mulched with straw was protected from the direct impact of raindrops. Corn stover was found more effective as a mulch than soybean residues. The corn stover left only 13 percent of the ground surface unprotected from raindrop impact, in contrast to 27 percent for the soybeam residues.

An average of 51 tons of soil per acre was lost annually from Shelby silt loam that was planted continuously to corn (29). But the rate of soil loss was reduced by 80 percent to an average of 9 tons per acre annually when corn was grown in a 3-year crop rotation of corn, wheat, and redclover-timothy. During the same period, an adjacent plot of bluegrass sod lost practically no soil.

The addition of wheat, redclover, and timothy to the cropping system provided better plant cover during the time they occupied the land. Here, the land was protected by plant cover except for the portion of the year when corn was grown. Corn was followed by wheat in October. Timothy was either planted in the wheat in the fall or the next spring, and redclover was planted in the spring. After the wheat was harvested, the clover and timothy continued to furnish good cover throughout the remainder of that year, all through the third year of the rotation, and until April of the corn year when ground was plowed. The effectiveness of plant cover in controlling erosion is illustrated in figure 4.

Pine and hardwood litter applied as mulch gave almost complete control of runoff and erosion over an 11-year period in North Carolina (7). Both forest cover and permanent sod were equally effective in controlling runoff and erosion. The use of wheat and lespedeza in a 4-year crop rotation with cotton and corn reduced soil loss to an annual average of 14.4 tons per acre for the rotation, compared with 31.2 tons from continuous cotton and 66.2 tons from bare land.

Semiannual burnings of a forest plot over a period of 7 years increased runoff more than a hundredfold, or nearly twice the amount lost from either cotton or corn in a 4-year rotation. Burning increased runoff losses from 0.03 to 22.0 percent of the rainfall. The amount of soil loss increased from practically none to nearly 8 tons per acre. The water drained faster from the cultivated watershed than from the protected, forested watershed.

The effectiveness of plant cover in controlling erosion and runoff is further emphasized by comparing soil and runoff losses from 1-, 2-, and 3-year old stands of hay. These losses were 6.53, 0.39, and 0.10 tons of soil per acre and 3.24, 0.38, and 0.12 inches of runoff, respectively, for the 1-, 2-, and 3-year stands (14).

Plant Cover and Losses of Plant Nutrients

Figures on the total amount of soil lost through erosion tell only part of the story. Soil erosion was shown to be a selective process (31, 32). As a result, the soil lost from the field usually contains higher concentrations of silt, clay, organic matter, and plant nutrients than the soil from which it was eroded (fig. 5). This may be illustrated further by citing a few specific examples.

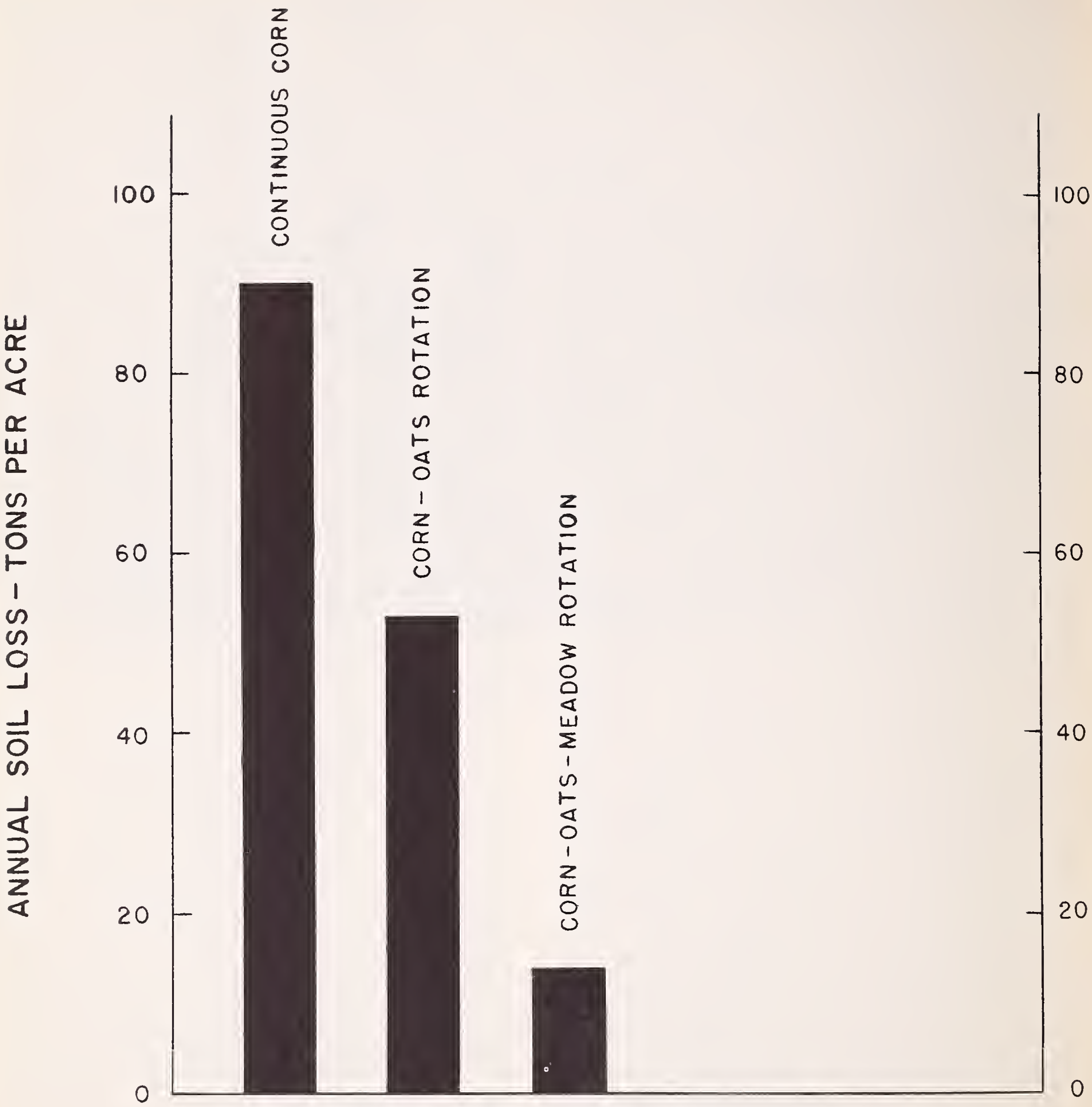

Figure 4.--Effect of cropping practices on erosion of Shelby silt loam.

Examinations made in Wisconsin in 1950 showed the concentration of nitrogen to be higher in the eroded soil material in each instance than in the parent soil (14). It was several hundred percent higher in many instances. The losses of soil and plant nutrients were closely related to the amount of plant cover on the land during the critical erosion-hazard period. For example, Fayette silt loam planted to spring oats lost 47,000 pounds of solids, 1,100 pounds of organic matter, 63.7 pounds of nitrogen, 4.05 pounds of available phosphorus, and 7.6 pounds of exchangeable potassium per acre. During the same period, a plot of Almena soil planted to corn lost 18,000 pounds of soil, 760 pounds of organic matter, 41.3 pounds of nitrogen, 1.43 pounds of available phosphorus, and 5.1 pounds of exchangeable potassium per acre. In contrast, Fayette silt loam protected by a hay crop lost only 120 pounds of soil, 15 pounds of organic matter, 1.3 pounds of nitrogen, 0.48 pound of available phosphorus,

TABLE 2.--Average pounds of plant nutrients in eroded material removed per acre annually during 2-year period, May 1, 1926, to May 1, 1928 (23)

Treatment	Nitrogen	Phosphorus	Potassium	Magnesium	Calcium	Sulphur
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Continuous bluegrass............	0.60	0.16	2.67	0.22	1.07	--
Rotation: corn, wheat, clover....	26.36	6.20	213.86	29.18	86.08	5.97
Continuous wheat................	32.39	9.42	264.00	42.67	106.23	8.55
Continuous corn.................	65.90	18.00	605.30	87.29	220.84	16.66
Fallow..........................	118.13	37.75	1,245.55	171.94	458.51	46.72

and 2.9 pounds of exchangeable potassium per acre.

The effect of plant cover on plant-nutrient losses by erosion is strikingly illustrated in table 2.

The selectivity of the erosion process is also well illustrated by the results of a single storm in Idaho, when the surface soil lost 6 percent of its silt, 7 percent of its clay, 20 percent of its organic matter, and 20 percent of its nitrogen (8). The surface soil contained 3.05 percent of organic matter before and 2.44 percent after the hard rain, whereas the eroded material contained 5.35 percent.

A field of Norfolk loamy sand in Alabama is so nearly level that it was thought to be free of erosion. Still, due to erosion, it lost 60 percent of the phosphate supplied in the form of 16-percent superphosphate over a period of 26 years (27) (fig. 6). The field was cropped to a 3-year crop rotation consisting of cotton, corn and oats during the 26-year period. The phosphates were floated off the field along with the clay fractions of the soil. It was also found that 400 pounds per acre of 16-percent superphosphate were required on the cultivated land to equal in crop production the effectiveness of 200 pounds applied to pastures.

Plant Cover Conserves Soil Organic Matter

Erosion quickly removes organic matter from the soil where there is not enough plant cover to protect it from the impact of raindrops (22). Without the protection of plant cover, it is difficult, if not impossible, even to maintain the organic-matter content of the soil.

This is shown by studies conducted on Shelby silt loam in Missouri during the 7-year period 1930 to 1937 (28). Soil and organic-matter losses through erosion were found to be inversely proportional to the amount of plant cover. For example, the organic-matter content of soil kept in fallow declined from 3.76 to 2.49 percent during the 7-year period, compared with an increase from 3.65 to 3.91 percent in the land kept in sod. The organic-matter content of soil planted continuously to corn declined from 3.31 to 2.64 percent, whereas the land planted to a 3-year crop rotation of corn, wheat, and clover showed a decline from 3.52 to 3.42 percent.

The treatment which permitted the greatest loss of organic matter also suffered the greatest soil and humus losses (28). Land kept in fallow lost a total of 12 tons of humus per acre during the 7-year period, along with 603 tons of soil. Land planted continuously to corn lost 7.4 tons of humus per acre in 371 tons of soil. Land planted to a 3-year crop rotation lost 39 tons of soil per acre, but adjacent land that was kept in sod lost only 1.5 tons per acre. It was estimated that, in order to replace the humus lost through erosion, 5.2 tons of clover hay per acre would be required annually on land kept in corn; 9.2 tons on fallow land; 0.6 ton on unfertilized land cropped to a 3-year rotation; and 0.4 ton on fertilized land planted to a 3-year rotation. It was also estimated that if erosion were eliminated, the nitrogen content of the fallow soil, and presumably the organic-matter content, could be maintained by the addition of 0.5 ton of clover hay per acre annually (1).

Based on the assumption that the organic-matter content of the eroded material was the same as that of the parent soil, the Missouri fallow plot lost 18 times as much organic matter by erosion as by oxidation (28). During 1935 and 1937, however, the eroded material contained on the average at least 40 percent <u>more</u> organic matter than the eroding soil.[2] Thus, it would appear that the loss of organic matter by erosion was more than 25 times as great as by oxidation. Results obtained on Marshall silt loam at Clarinda, Iowa, during the same period paralleled those obtained on Shelby silt loam at Bethany, Mo., but at a slightly lower level (28).

Sod crops are sufficiently effective in restoring soil organic matter to offset the destructive influence of clean cultivation and summer tillage (2). Data from Missouri show clearly the destructive influence of summer fallow and, in contrast, the increase in organic matter obtained by using sod crops. When sod was used in a 3-year crop rotation, with manure from the crops returned to the soil, there was

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[2]Unpublished data of D. M. Whitt. Letter dated Aug. 21, 1952.

Figure 5.--Organic matter, silt, and clay "blasted" loose by falling raindrops were floated downhill by runoff water in this Illinois cornfield to be deposited in depressions or floated off the field. Soil organic-matter losses by erosion in Missouri were estimated to be 25 times as great as by oxidation.

no serious decline in the content of organic matter (table 3).

The addition as a mulch on Shelby loam of 2.5 tons of dried and chopped redclover per acre annually over a 15-year period resulted in a net gain of 497 pounds of nitrogen (1). The nitrogen content of an adjacent area, which received no clover, declined a total of 115 pounds per acre during the same period. The soil on both plots was spaded in June of each year. After spading, the chopped clover was spread over the surface of one series of plots and left until June of the next year. The other series of plots was left fallow. An average of 40.1 pounds of nitrogen per acre were added to the nitrogen in the soil each successive year where the 2.5 tons per acre of organic matter were spread on the surface of the ground. Almost 0.5 ton of clover per acre annually would have been needed to maintain the untreated soil at its original nitrogen level.

Soil at Guthrie, Okla., which contained an average of about 46,000 pounds of organic matter per acre to plow depth (7 inches) in 1931, suffered an average annual net decline of 1,860 pounds per acre when planted only to cotton during the period 1931 to 1940 (9). That is, these plots lost both the organic matter returned as crop residues and 1,860 pounds annually from the original organic matter in the soil.

TABLE 3.--Gains and losses in soil organic matter (in pounds per acre of surface soil) during 17 years, on areas under different systems of cropping and management.

Crop and management	Organic matter	
	Gain	Loss
	Pounds	*Pounds*
Rotation: corn, wheat, clover (all crops removed	---	800
Rotation: corn, wheat, clover (manure equivalent returned)	3,200	--
Rye and cowpeas (turned under as green manure)	1,200	--
Rye turned under--summer fallow	--	14,400
Redclover continuously--all crops removed	3,600	--
Redclover continuously--all crops turned under	9,600	--
Alfalfa continuously--all crops removed	10,400	--
Grass sod, clipped--nothing removed	10,000	--

Figure 6.--Fertility erosian in a cultivated field in New Jersey. Organic matter, silt, and clay were sploshed from the sand by the impact af falling raindrops. The woshed sand, appearing as light-calared deposits between the rows, was left in the furraws. A light-textured sail in Alabama lost 60 percent of oll the phosphoric acid applied as superphasphate over a 26-year period by this process.

When the plots were planted to a 3-year crop rotation of cotton, wheat, and sweetclover, however, the net decline was reduced to 940 pounds per acre. Soil with a sod cover of bermudagrass accumulated organic matter at the rate of 1,700 pounds per acre annually, instead of suffering a decline.

Plant Cover and Soil Aggregation

Aggregates are the structural elements of soil. Their presence and maintenance are essential to good soil tilth and a high state of productivity. Their formation in soils depends upon adequate supplies of biologically active organic matter (34).

The humate fraction of the organic colloids produced by soil micro-organisms, in the course of the decomposition of organic matter, appears to be the major factor contributing to the formation of soil aggregates. These organic colloids, or binding agents, are distributed uniformly throughout the soil and are adsorbed to colloidal clay particles. They effectively produce stable aggregates, perhaps by electrochemical union with organic colloids. Evidently they are bound through the carbon linkage "bridge" between reactive groups on the polymer. This reaction is believed to take place mainly by polar adsorption, resulting from the decomposition of fresh organic matter. Joined to the soil particles, the humate fraction or hydrophilic colloids serve as bridges between the particles, keeping them from separating yet at the same time holding them apart so they won't pack down tight.

Since certain other groups of soil micro-organisms break down these organic colloids as they are formed, it is necessary to keep a continuous supply of fresh organic matter in the soil if a high state of aggregation is to be maintained. This can only be accomplished by using sod or mulches, to which fresh materials are added frequently to produce continuous plant cover (3, 13, 34, 37).

Over a 4-year period, surface application of organic material caused a greater increase in the size and number of large water-stable soil granules in Hagerstown silt loam than did incorporation of the same materials in the soil (3). The increase in the soil organic-matter content that resulted from the surface application of these materials was most pronounced in the 0 to 1-inch surface layer. Cornstalks and soybean residues used as mulch increased the number of all sizes of aggregates in the soil (37). Straw mulch was particularly effective in promoting the formation of large aggregates.

The amounts of aggregates of various sizes were strikingly different under sod, mulch, and cultivation treatments in the soil of a peach orchard on Wooster silt loam, which had been under treatment for 28 years, and an apple orchard on the same type of soil, which had been under treatment for 44 years (13). Three types of cultural treatments were used on each

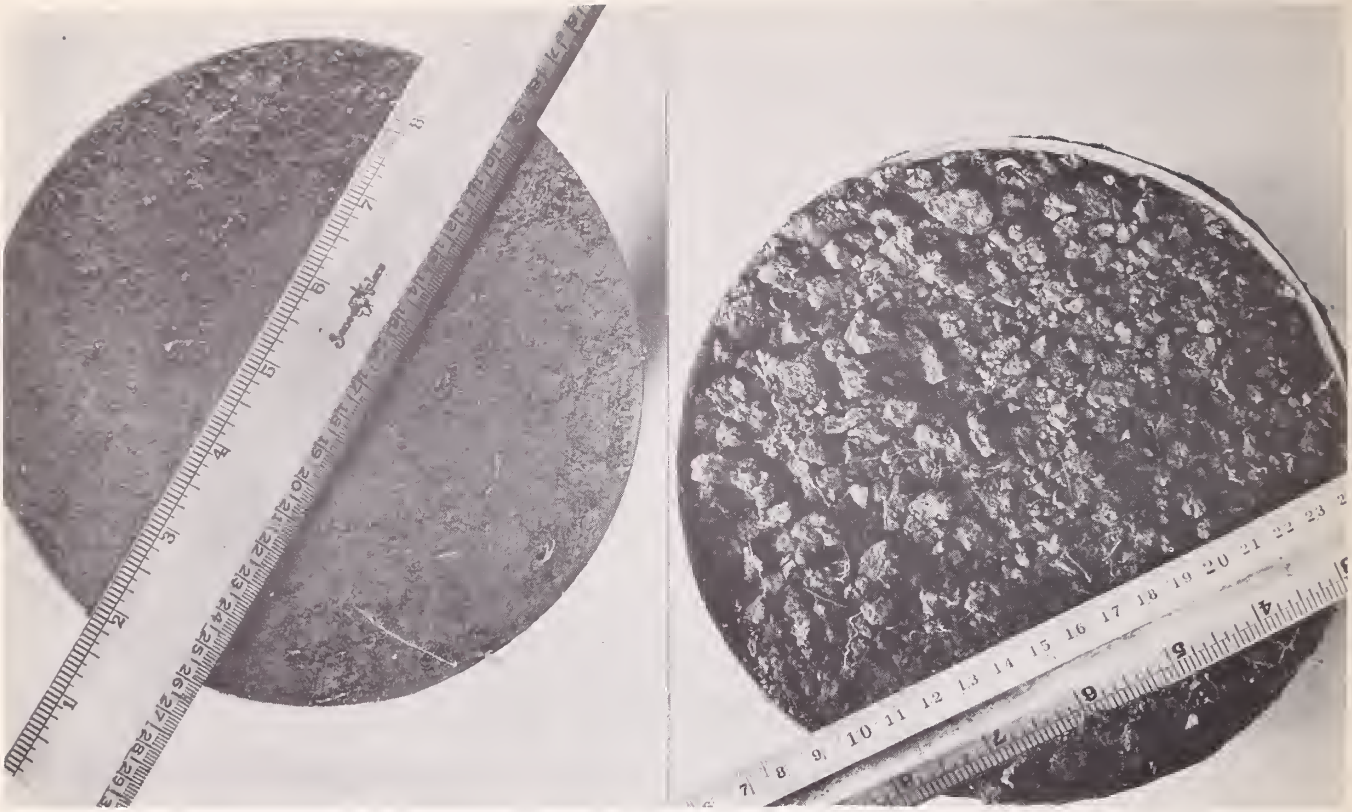

Figure 7.--Plant cover aids the formation and maintenance of aggregates which are essential to good soil tilth. The photographs above are of two samples of Muskingum silt loam taken just across a fence from each other: Right, this was taken from an orchard which had been in bluegrass sod for a number of years; Left, this came from a field that had been in cultivation for more than 40 years.

orchard. One series of plots was planted to cover crops, a second was left in bluegrass sod, and the third was mulched with straw. The cover crops were plowed down and renewed in accordance with usual practices. The straw mulch was renewed frequently enough to maintain a thick covering.

The amounts of aggregates of various sizes were strikingly different (fig. 7). The mulched plots showed the greatest amount of aggregates among the larger sizes. Sod resulted in almost as much aggregation but the cultivated soil contained only small aggregates. Even in the A horizon there were few soil aggregates over 1 mm. in diameter under the cultivation treatment. In contrast, approximately 28 percent of the dry weight of the soil under mulch and 23 percent under sod in the apple orchard were composed of aggregates over 1 mm. in diameter. The same general trend occurred in the peach orchard. The state of aggregation was in fairly close relationship to the percentage of soil organic matter except for the high aggregate formation under wheat-straw mulch in another series of treatments which had been underway for 7 years (13).

Plant Cover and Infiltration

The sharp impact of raindrops, as they strike bare earth during heavy rains, shatters the clods and soil crumbs and breaks down the soil structure. The beating, churning action of these drops compacts the fine soil particles into a nearly impervious layer of surface mud, to cause "puddle erosion" (35). The compacted surface layer becomes denser and more nearly impervious as it strains colloids and other particles from the turbid rainwater that filters down from the surface. This layer is the most important factor affecting the intake of water by the soil. It decreases infiltration (fig. 8), increases runoff and soil loss, and paves the way for gully formation. Puddle erosion can be prevented by maintaining enough plant cover on the surface to shield the soil. This cover may be composed of growing plants or plant residues, or both. It is extremely important to have ample cover well distributed over the surface of the ground, so that the beating raindrops cannot break down soil structure and form a nearly impervious layer of soil at the surface.

Studies conducted in Missouri indicate that plant cover in the form of crops is another important factor in maintaining favorable moisture conditions in the subsoil. The beneficial effects of sods turned under for corn crops have usually been ascribed to an improved supply of nitrogen. Possibly, however, the important factor has been the accumulated moisture in the subsoil.

Grass crops absorbed 87.4 percent of the rainfall and a 3-year crop rotation with 1 year of sod absorbed 85.5 percent, but land continuously in corn absorbed only 69.6 percent, according to trials extending over 14 years (23). This was the equivalent of an increase in rainfall of 7.2 inches for land in grass and 6.4 inches for land under the crop rotation, as compared with land continuously in corn. The difference in crop yield was more significant than these figures indicate, since two-thirds of the annual rainfall occurred during 6-months of the growing season--or the period when differences in rainfall mean differences in yields.

Much of the extra water absorbed by soil protected by plants moves beyond the zone of consumption by the shallow grass roots and is stored there. Thus, the deeper soil layer (such as the 24- to 36-inch layer) under sod contains more water than the same layer under tilled soil. Moisture in two similar soils, not far from those in the erosion study cited above, are interesting from this standpoint--especially for the years 1934 and 1936, which were seasons of deficient rainfall. Table 4 gives the moisture content as the percentage of moisture in the successive 1-foot layers to a depth of 3 feet.

The 24- to 36-inch layer was much drier under the cultivated soil. Since considerable time always elapsed after rain before it regained moisture, the total water content of this layer under cultivated soil never equaled that in the 24- to 36-inch soil depth under sod. The 0-12-inch layer under sod had a lower moisture content than that under cultivation during 1 month (March 1936). Otherwise, the moisture supply in the 12- to 24-inch and 24- to 36-inch layers was always greater under sod. The most pronounced differences were at the 24- to 36-inch depth. These differences mean that, on the average, the 24- to 36-inch layer under sod is storing the equivalent of a 1.2-inch rain annually, which it may supply to the sod crop or to the deeper roots of the following crop in the drier summer season.

Surface mulching in Pennsylvania resulted in maintaining an optimum soil-moisture content even during the driest part of the growing season (3). Three and four years of mulching with manure, straw, sawdust, corn stover, oak leaves, or pine needles resulted in complete control of surface runoff and an infiltration capacity of 3 inches per hour or more. The chief value of mulch in controlling runoff and erosion was in its protective effect.

An abrupt decrease in infiltration capacity followed the incorporation into the soil of a heavy cover crop in orchards in Pennsylvania (4). Several months were required to restore a soil-plant relationship that favored a high infiltration capacity. Removal of the cover crop from the soil surface, either by incorporating it into the soil or by mowing it and removing the clippings, increased runoff. The actual ground coverage by plant material and the number of depressions for water detention were the two factors most important in controlling runoff. Wheat straw, soybean residue, and corn stover used as mulch on a permeable prairie soil in Illinois greatly increased the infiltration rate and reduced the amount of water lost as runoff (18).

Plant Cover and Fertilizer

Adding fertilizer to the soil aids in reducing erosion losses because it produces more plant cover. The fertilizer stimulates early growth, thus hastening the date when the cover becomes effective, and increases the amount and density of cover by increasing total plant growth. Besides helping to control erosion through the production of more vegetation, the use of fertilizer results in higher yields.

Two plots in Wisconsin were planted to a 3-year crop rotation of corn, oats, and hay. The oats in one plot were fertilized. The average annual per-acre soil loss over a 5-year period was 47.21 tons under the unfertilized crop rotation and 13.13 tons where fertilizer was used (15).

The use of 200 pounds of 5-10-5 fertilizer per acre annually on land planted continuously to corn in New York reduced the loss of water by one-third and the loss of soil by two-fifths over a 9-year period, compared with unfertilized cornland (19). The unfertilized corn plot lost 9.5 percent of the rainfall as runoff and 5,934

TABLE 4.--Moisture content at successive depths under sod and under cultivated soil (2)

Date	0-12 inch		12-24 inch		24-36 inch	
	Sod	Cultivated	Sod	Cultivated	Sod	Cultivated
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
April 1934	27.18	25.23	29.90	24.61	26.11	16.58
November 1934	33.80	31.70	31.90	30.80	32.60	24.80
March 1936	26.30	27.80	28.20	28.90	28.30	23.00
November 1936	27.00	26.80	28.50	27.30	27.80	19.80
April 1937	32.90	28.30	30.00	28.60	30.70	23.40

Figure 8.--Plant cover preserves the open porous structure at the surface of the ground, which favors rapid infiltration. Equal amounts of soil were placed in the cup on top of each jar. Mulch cover was placed on the soil in the cup to the left; the other was left bare. Rain was then played on the soil in the two cups for about 7 minutes. The greater amount of water in the jar with the mulch cover shows how the mulch cover increased water intake.

pounds of soil per acre annually. The fertilized plot lost 6.4 percent of the rainfall as runoff and 3,552 pounds of soil per acre.

Unfertilized Shelby silt loam in Missouri, planted to a 3-year crop rotation of corn, wheat, and hay, lost an average of 8.81 tons of soil per acre annually during a 7-year period, compared with a loss of 3.69 tons for similar soil that was fertilized and planted to the same crop rotation (38). A comparison of soil loss while the land was in wheat and oats, both with and without fertilizer, illustrates the effectiveness of fertilizer in reducing losses by erosion. Soil loss from land in wheat was reduced by one half, while the loss from oats was reduced more than one-half, as a result of the increased cover obtained by the use of 200 pounds of fertilizer per acre (29) (fig. 9). The use of the fertilizer increased the wheat yield 91 percent and the oat yield 77 percent on the average over a 7-year period.

Plant Cover and Soil-Depleting and Soil-Conserving Crops

Much has been said in recent years about soil-depleting and soil-conserving crops. Actually, the difference between the two kinds of crops is one of plant cover on the land. The soil-depleting crops do not provide enough cover during the summer period of erosion-producing rains (fig. 10).

The plants of the soil-depleting crops take less of the organic matter and minerals from the soil than do the soil-conserving plants. But the cultivation that is needed and the way that the soil-depleting plants grow encourage erosion, so that the total loss of nutrients from the soil is high. Soil-conserving plants, on the other hand, provide good plant cover once they are established. Although these plants use more of the nutrients from the soil, they prevent losses through erosion and also add enough organic matter to improve the soil's fertility.

The comparative amounts of plant nutrients removed by hay crops and the grain of the corn and oats crops in a 5-year crop rotation with 3-years of hay and in a 3-year crop rotation are shown in tables 5 and 6.

As previously stated, soil at Guthrie, Okla. with a sod cover of bermudagrass accumulated organic matter at the rate of 1,700 pounds per acre annually from 1931 to 1940 (10). In contrast, plots that were planted continuously to cotton during the same period lost the organic matter returned as crop residues and also 1,860 pounds of the original organic matter reserve each year. Table 5 (25) gives the average pounds of plant nutrients lost by erosion annually during a 2-year period in Missouri.

One of the most important benefits derived from maintaining enough cover is the preservation of this organic matter. It has been generally believed that oxidation was responsible

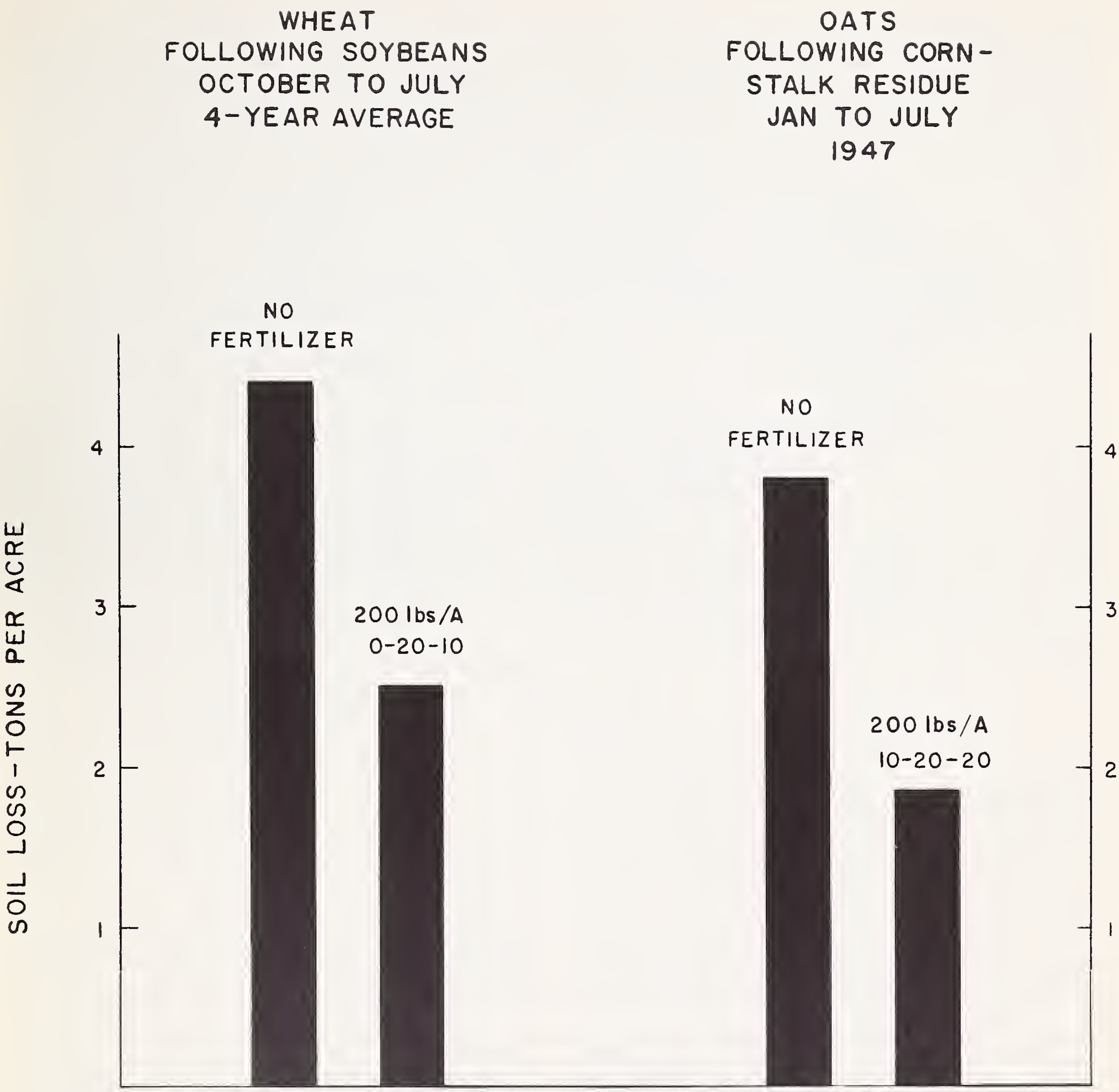

Figure 9.--Effect of fertilizer on erosion of land planted to small grain.

for the major losses of soil organic matter. It is now known however, that soil erosion enjoys this distinction. Investigations in Missouri showed the loss of soil organic matter by erosion to be 25 times as great as that by oxidation. Since organic matter is the source of the soil's nitrogen, the loss of the nitrogen in the organic matter removed by erosion is a controlling factor in crop yields.

This was illustrated by results from the project at Clarinda, Iowa,[3] where the addition of 180 pounds of nitrogen per acre in 1952 to plots that had grown corn continuously for the past 20 years eliminated the trouble which caused low yields. Since 1932, corn has been grown continuously on one series of plots and in a 3-year rotation of corn, oats, and meadow on another. The corn in each series received the same fertilizer treatment until 1952. The fertilizer treatment was the same again in 1952 except for

[3]This project was transferred from the Soil Conservation Service to the Bureau of Plant Industry, Soils, and Agricultural Engineering in 1953.

TABLE 5.--Average pounds per acre of plant nutrients removed annually by the grain of corn and oat crops and alfalfa-brome hay in a 5-year rotation of corn, oats, hay, during 1947-50

Crop	Calcium	Phosphorus	Nitrogen	Potassium
	Pounds	*Pounds*	*Pounds*	*Pounds*
Corn	0.35	9.46	52.55	10.86
Oats	2.01	7.36	42.82	8.92
Hay	42.90	13.52	109.31	103.43

TABLE 6.--Average pounds per acre of plant nutrients removed by the grain of corn and oats and by hay in a 3-year rotation of corn, oats, and hay

Crop	Calcium	Phosphorus	Nitrogen	Potassium
	Pounds	*Pounds*	*Pounds*	*Pounds*
Corn	0.31	8.40	46.67	9.64
Oats	1.68	6.15	35.81	7.46
Hay	32.85	7.55	65.27	65.27

TABLE 7.--The average annual yield of corn in bushels per acre by 5-year periods and for 1952 for corn grown continuously and in a 3-year crop rotation during the period 1932 to 1951, inclusive, and 1952.

Croppings systems	Average annual yields in bushels per acre				
	1932-36[1]	1937-41	1942-46	1947-51	1952
Continuous corn	23.9	32.5	23.9	17.8	103.0
Rotation	25.8	57.0	72.0	83.9	98.4

[1] Includes the drought years 1934 and 1936 when the crop was a failure.

the fact that the continuous corn plots received 180 pounds of nitrogen per acre. The yields in 1952 were 103.0 bushels per acre on the continuous corn plots and 98.4 on the rotation plots.[4]

These results suggest that if erosion losses are prevented, it will be feasible to grow corn or other soil-depleting crops successfully year after year by proper use of fertilizer and plant cover. The heavy stalk production accompanying high corn yields should provide enough cover if properly utilized. Elimination of fertility losses by erosion will plug the greatest drain on plant nutrients and make soil building a relatively simple process either with or without the use of crop rotations.

The average annual yields of corn in bushels per acre by 5-year periods and for 1952 for both series of plots are given in table 7.

Beginning the second 5-year period, the yield on the continuous corn plots declined from 32.5 bushels per acre to 17.8 for the fourth 5-year period. During this time the yield on the rotation plots increased from 57.0 bushels per acre for the second 5-year period to 83.9 for the fourth. The difference between the yields of these two series of plots also became greater with time. This difference was 1.9 bushels for the first 5-year period, 24.5 for the second, 38.1 for the third, and 66.1 for the fourth.

Except for nitrogen, the figures presented in table 5 do not show corn to be soil-depleting in comparison with hay. Since the hay crop contained alfalfa, it is presumed that the nitrogen removed in the harvested hay was approximately equal to the amount taken from the air by the crop. Thus the original supply of nitrogen in the soil was not changed. However, the nitrogen removed by the corn crop was a net loss to the soil's supply.

Similar figures are given in table 6 for the crops grown in a 3-year crop rotation.

[4]Personal communication with F. W. Schaller, dated October 31, 1952.

Figure 10.--Cotton plonts in this field did not furnish enough cover for adequate protection of the soil against the impact of falling raindrops. Land planted continuously to cotton in Oklahoma lost the equivalent of all the crop residues left on the ground ond 1,860 pounds per acre annually of the soil's originol supply of orgonic matter over a 10-yeor period. It also lost an overage of 18.9 tons of soil per ocre annually by erosion.

Summary

Nature employs two distinct steps to build soil. These are the "holding" and "developing" actions, which operate simultaneously. They are performed by the countless thousands of types and species of plants that inhabit the earth. The "holding" action keeps the soil in place and prevents its removal by the erosive agents, wind and water. The "developing" action changes the parent rock into soil. These actions operate in such a way as to build soil from the top downward.

The primary function of plant cover in the "holding" action is to protect the soil from erosion by absorbing the destructive energy of wind and falling raindrops. Plant cover reduces the velocity of the surface wind currents to such an extent that they no longer possess energy enough to start the saltation movement (the major factor in wind erosion). It also traps soil particles from adjacent areas that may be subject to wind erosion.

For water-erosion control, plant cover serves as a springy cushion to intercept falling raindrops, thus preventing them from striking the ground surface before being relieved of their kinetic energy. This prevents them from tearing the soil particles loose, to be carried away in the runoff water. The raindrops are also prevented from puddling and sealing the soil surface. This enables the soil to maintain a high infiltration rate and reduces runoff.

By maintaining a continuous supply of easily decomposable organic matter on the surface of the ground, plant cover produces and maintains good soil tilth. This is achieved by supplying, in the form of leachings, the humate fractions of organic colloids which are responsible for the production of aggregates or crumbs that are essential to good structure. Plant cover also keeps to an absolute minimum the loss of plant nutrients and soil organic matter by erosion. By keeping erosion losses to negligible quantities, it is possible to hold the soil in place and build it up at the same time.

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